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Sarah Brotherton • Chris B. Joyce • Jörn P. W. Scharlemann

S. Brotherton • J. P. W. Scharlemann (✉)
School of Life Sciences, University of Sussex, Brighton BN1 9QG, UK
e-mail: j.scharlemann@sussex.ac.uk

S. Brotherton • C. B. Joyce (✉)
Centre for Aquatic Environments, School of Environment and Technology, University of Brighton, Brighton BN2 4GJ, UK
e-mail: c.b.joyce@brighton.ac.uk

J. P. W. Scharlemann
United Nations Environment World Conservation Monitoring Centre, 219 Huntingdon Road, Cambridge CB3 0DL, UK

Abstract

The global offtake of wild animals is valued at US$400 billion annually and supports the livelihoods of 15% of the global population. Wetlands are amongst the most important ecosystems globally, but offtake may represent a substantial pressure. This study assessed the availability of information and evaluated the offtake of wild animals from wetlands by focussing on fish and waterbirds. A literature search identified 2726 studies on wetland offtake. Scoping of these resulted in 82 studies that contained quantitative information on fish or waterbird offtake.

Fishing offtake statistics for inland waters are collated nationally by some governments, but other sources of information are few. Reporting of fish offtake for species or across scales was constrained by insufficient detail, even in relatively well-documented countries such as Bangladesh. Although government hunting statistics from Europe and North America were available, there was little waterbird data from less economically developed countries. The case of Canada indicated that the species richness and composition of waterbirds taken varied between indigenous subsistence and recreational hunting communities. Hidden (unquantified) offtake, of both fish and waterbirds, hinders obtaining precise data for offtake, which may threaten the conservation of species and the sustainability of wetland ecosystems.

Keywords Harvesting • Hunting • Fishing • Sustainable • Bangladesh • Canada

Introduction

The global harvest of wild animals from land and sea has a commercial value of over US$400 billion annually and supports the livelihoods of 15% of the global population (Milner-Gulland et al. 2003; Brashares et al. 2014). Throughout human history, wild animal and plant species have been taken and used for food, fur and skins, fuel, traditional medicine, rituals, pets, sport, objects of scientific interest and curios, and as food for farmed animals, such as wild fish used as feed in aquaculture. Even today, wild species are the main source of protein for more than a billion people (Brashares et al. 2014). Advances in harvesting technology (e.g. guns, sonar use in fishing, wireless communication, Global Positioning System) and refrigeration have increased the frequency and quantity of wild species harvests in recent decades (Tsuji and Nieboer 1999). Overexploitation, the harvesting of wild species at unsustainable rates, is considered the biggest driver of biodiversity declines for more than 8,000 threatened or near-threatened species assessed by the International Union for Conservation of Nature (IUCN) Red List (Maxwell et al. 2016). Exploitation of wild species can lead to extinctions, with ultimately negative impacts on ecosystem functioning and human wellbeing.

The taking, exploiting or harvesting of animals from the wild, referred to here as offtake, is beginning to be recognised by policymakers and reflected in international and national policies. While information is available for marine offtake (e.g., Pauly 2007), recent assessments of threats to species highlighted the need for better knowledge on the use of biological resources, especially from terrestrial and freshwater ecosystems (Pereira et al. 2012; Joppa et al. 2016). Information on wild animal offtake and use is critical for reporting towards multiple international conventions and targets, including the Convention on Biological Diversity (CBD) Aichi Targets (e.g. Strategic Goal B) (UNEP and CBD 2010), the UN Sustainable Development Goals (especially trade-offs between SDGs 2 Zero Hunger and 15 Life on Land) (UN General Assembly 2015), the Food and Agriculture Organisation of the United Nations (FAO) Food Security Indicators, and also to inform national wildlife and food security policies.

Wetlands are vitally important for wildlife, supporting a richness of global biodiversity disproportionate to their limited extent (WWF 2018). Wetlands are areas that are inundated or saturated by surface or groundwater at a frequency or duration sufficient to support vegetation adapted for saturated soils. They can be natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt up to 6 m deep (United Nations Educational Scientific and Cultural Organization (UNESCO) 1971). They encompass a range of inland and coastal ecosystems, including rivers and lakes, floodplains, swamps, marshes, peatlands, mangroves, and rice fields. Wetland ecosystems contribute to peoples wellbeing and support vital services, including nutrient cycling, carbon storage, water purification, flood attenuation, and recreation (Russi et al. 2013). Their valuable provisioning services include drinking water, building materials, forage, fuel and food, such as fish and rice, thereby contributing to water and food security.

The global value of the provisioning services for coastal and inland wetlands, including rivers and lakes, is likely to be equivalent to at least Int\$3.33 trillion yr^{-1}, representing almost 5% of global GDP (Costanza et al. 2014). This is based on a cautious average of Int\$2,190 ha^{-1} yr^{-1} (2007 values) (de Groot et al. 2012) and a conservative estimate of the global extent of wetlands at 15.2×10^8 ha (Davidson and Finlayson 2018). The food service value alone is on average Int\$610 ha^{-1} yr^{-1} (de Groot et al. 2012), equivalent to Int\$927 billion yr^{-1} for the estimated global wetland resource. Animals taken from wetlands constitute a major source of protein in many human diets globally (Youn et al. 2014), especially where animal husbandry is less prevalent, or wetlands are not suitable for grazing livestock. Subsistence fishing, where fish are caught and consumed by the fisher and family, provides an important source of high-quality protein and micronutrients in many low-income countries (Youn et al. 2014). Fishing in wetlands can also generate income for rural communities and represent a vital source of employment for many women (Cooke et al. 2016). The fishing services at the 320,000 ha Lake Chilwa wetlands in Malawi were valued at over US$18 million in 2002 (Schuyt and Brander 2004). Sports fishing on wetlands has been valued at US$374 ha^{-1} yr^{-1} and recreational hunting of birds and game at US$123 ha^{-1} yr^{-1} (Schuyt and Brander 2004). Where hunting and fishing for sport or recreation requires the purchase of licences, this can generate substantial income, such as the £21 million (US$27 million) spent on fishing licences in England in 2015-16 (Environment Agency 2019).

The biodiversity of wetlands is amongst the most threatened of any ecosystem, and human offtake may represent a significant pressure affecting wetland-dependent taxa. Recent indicators suggest an 83% decline in global populations of freshwater species since 1970 (WWF 2018). Fish and waterbirds are among the most important indicators of wetland health and functioning (Weller 1999; Batzer and Sharitz 2014). The Ramsar Convention on Wetlands (2018) reports that 29% of freshwater fish species and 18% of waterbirds are threatened. It is estimated that inland wetlands including rivers and lakes support about 15,000 species of fish (Lévêque et al. 2008), of which over half are threatened, endangered, or extinct in the wild (He et al. 2018). In the 20th century, freshwater fish had the highest global extinction rate of any vertebrates (Burkhead 2012). Overexploitation now accounts for 55% of all threats to fish populations (WWF 2018). Waterbirds depend on inland and coastal wetlands for breeding and/or food, and include some of the most conspicuous and iconic wetland wildlife, including ducks, geese, swans, wading birds, herons, cranes, and flamingos. Population trends for waterbirds globally indicate that 38% of species are in decline, with Anatidae (ducks, geese and swans) and Raillidae (rails, crakes, coots etc.) the most threatened (Wetlands International 2012). The IUCN lists 58 wetland bird species that are globally endangered by hunting, with a further 68 species categorised as vulnerable (IUCN 2018). In China, 71% of endangered waterbirds are threatened by hunting and historical studies suggest up to 50% of overwintering birds were taken annually from some floodplains (Wang et al. 2018). Many waterbirds are also taken on migration along flyways between winter feeding and summer breeding wetlands (Boere and Piersma 2012).

In addition to fish and birds, offtake for a variety of uses represents a substantial threat to a wide range of wetland vertebrate and invertebrate taxa. The IUCN lists 53 mammal species of wetland habitats as vulnerable or threatened by hunting and trapping (IUCN 2018). Examples of wetland-dependant mammals taken include otters that are trapped and hunted for meat as well as perceived pest control in Africa and Asia, and hippopotamuses, which are often illegally hunted for meat and ivory, especially since bans on the trade in elephant ivory (Veron et al. 2008). Amphibians are taken for food and the pet trade (Vences and Köhler 2008) with, for example, the USA importing over 14.7 million 'wild-caught' amphibians between 1998 and 2002 (Schlaepfer et al. 2005). Freshwater reptiles are amongst the most threatened wetland taxa (Ramsar Convention on Wetlands 2018) and turtles are the most exploited of the reptiles, primarily for their meat, eggs, medicinal use and the pet trade. Consequently, 30 wetland turtle species are listed as either vulnerable, endangered or critically endangered (IUCN 2018). A diversity of invertebrate species, ranging from crustaceans to molluscs and insects, are taken from wetlands, likely in very large numbers. Almost 50,000 tonnes of aquatic invertebrates, not including crustaceans and molluscs, were caught globally in 2009, mostly in China (Welcomme 2011). Water beetles, for example, are consumed and used in traditional medicines particularly in Asia (Jäch and Balke 2007). Historic examples of overexploitation include freshwater leeches, mussels, and crayfish (Strayer 2006), and over 30% of non-marine mollusc and crayfish species are globally threatened (Ramsar Convention on Wetlands 2018).

The importance of wetland animals is not limited to their resource value for humans; they also fulfil vital functions within wetland ecosystems that offtake may disrupt. These include: dispersal of plant seeds by mammals and birds (Green et al. 2007); consumption of weed seeds and invertebrate pests by birds in agricultural wetlands (Sandilyan and Duraimurugan 2013);

herbivory by birds that maintains vegetation structure and diversity (Green and Elmberg 2014); nutrient cycling and aeration of sediments through bioturbation by crustaceans, amphipods and gastropods (Covich et al. 1999; Vaughn and Hakenkamp 2001); and ecological engineering by beavers that creates new wetlands (Rossell et al. 2005).

Given the global importance of wetlands and their services, the decline in their biodiversity (Ramsar Convention on Wetlands 2018), and the pressures on endangered wildlife, it is vital that the offtake of wild animals from wetlands is evaluated. Unlike marine systems, for which offtake and its sustainability have long been of interest (e.g. Pauly 2007), there is limited research on animal offtake from wetlands with a global perspective. This paper assesses the availability of information and evaluates the offtake of wild animals from wetlands by focussing on two key taxa: fish and waterbirds. Its objectives are to:

i) Systematically search and critically review the global literature and data sources on waterbird and fish offtake from wetlands to ascertain their availability and scope, and

ii) Analyse the data and other information reviewed to present cases that exemplify and elucidate key trends and patterns in offtake from wetlands.

Methods

Searches for information on wetland offtake, with a focus on fish and birds, were conducted between May and July 2018 by retrieving relevant literature using a series of target words combined across themes in search strings in Web of Science and Google Scholar (**Table 1** Target words used in Web of Science and Google Scholar searches). Boolean operators AND and NOT were used to combine words and exclude other terms. A wildcard (*) was used to incorporate multiple word endings (e.g. fish* er, ing, ery, etc). The full range of years available was used in all searches, extending back to 1900. When less than four results were returned in a search of article or report titles only, the search was expanded to include topic so that keywords would also be incorporated. Additional information, such as from non peer-reviewed reports, was obtained following recommendations from an expert advisory panel, which met in July 2018.

Screening for the most relevant information involved evaluating titles and abstracts of all publications retrieved from the initial search results in relation to the following five criteria. All relevant documents were identified and stored.

Subject: The scope of wetlands included was based upon the Ramsar classification of wetland types (Ramsar Convention 2012), adapted by Davidson and Finlayson (2018). This comprises three main types of wetland: *inland natural*, used to assess both fish and bird offtake, and *coastal natural* and *human-made*, used for birds only to avoid likely cases of marine fisheries and aquaculture. The extent of inland natural wetlands is dominated by peatlands, lakes, and marshes and swamps (including floodplains), which together form over 80% of the global area of surface inland wetlands, with a smaller area of rivers and streams (Davidson and Finlayson 2018). Natural coastal wetlands include saltmarshes and tidal flats, which together form over 60% of the global coastal wetland area (Davidson and Finlayson 2018), as well as mangroves and seagrass beds. The main areas of human-made wetlands are rice fields and water storage bodies such as reservoirs and ponds.

Taxa: The focal taxa were fish and waterbirds that depend upon wetlands to complete their life cycle. For fish, this included wholly freshwater and diadromous species, both those that migrate from marine to freshwater to breed, such as the anadromous salmonids, and catadromous species like eels that return from freshwater to the sea to reproduce. Waterbird species that use inland and coastal wetlands were included. Many waterbirds are mobile between inland wetlands such as floodplains, wet grasslands and mires, where they might breed, and coastal wetlands such as marshes or lagoons where they might stop on migration or overwinter (Weller 1999). Examples include ducks and wading birds. Some sea ducks may also use inland wetlands, for example during winter, inclement weather, or to breed (Duda et al. 2018).

Geography: The search was applied globally. Data from multiple sources for the same geographical area were commonly found (e.g. waterbird hunting statistics for European and North American countries, and river basin data, often comprising several countries, for fish).

Date: No date restrictions were applied. Data covering multiple years were of particular interest as they enabled assessment of temporal trends.

Language: The search was conducted, and most information was returned, in English. However, some government hunting statistics and data sets were translated into English to enable them to be integrated into the assessment.

Finally, the literature was scrutinised to identify case study issues of interest, namely reasons for offtake, geographical (e.g. country) or species-specific studies, examples of (un)sustainable offtake, and statistical analysis. Most of the quantitative information on fish and bird offtake reported in the literature was traced to two main data sources. The FAO maintain national records of inland fisheries from 1950 onwards in the ‘fishstat’ database (FAO Fisheries and Aquaculture Department 2016). For waterbirds, governments of many of the more economically developed countries have open access data on hunting, some going back several decades. The European Federation for Hunting and Conservation (https://www.face.eu/) provides web links to national statistics for hunting in Europe.

Results of the literature search

The initial literature searches resulted in 2726 articles or reports (subsequently called studies) being identified. The most successful search strings with more than 200 studies each in Web of Science were: 'floodplain* AND fish*'; 'fish* AND exploit* NOT marine NOT reef NOT coast'; 'illegal AND bird' and 'inland AND fish*'.

Reviewing the studies highlighted a variety of terms being used to describe the taking of animals by humans from the wild, including: use, exploit, overexploitation, take, offtake, hunt, harvest, fish and capture. Some terms were used more frequently in relation to particular taxa, such as 'capture' for fish and 'hunt' for birds, while others such as 'harvest' were used commonly for both. However, nuanced differences in application or implied meaning for some terms were apparent between taxa. For example, the term 'exploit' often suggested negative connotations within studies on waterbirds, but for fish tended to imply their beneficial use as a resource, unless overexploitation was explicitly mentioned. To overcome ambiguity, here the term 'offtake' is used to encompass this diverse lexicon and 'overexploit/ation' when discussing offtake that is known or suspected to be unsustainable. Offtake that is acknowledged in studies but is unquantified or otherwise unreported officially is described as 'hidden'.

Screening of the identified studies resulted in 82 being extracted as containing data, or other quantitative information, on fish or waterbird offtake in wetlands (Table S1 & S2).

Fish offtake

Forty-one relevant studies on fish offtake were collated, of which 24 (59%) were peer-reviewed. Floodplains were the most common type of wetland identified (63%) and almost half of the studies were specific to single countries or river basins, of which half of these were site-specific. Most studies (83%) used the term 'exploit' to describe the offtake of fish, often interchangeably with 'harvest' (73%). The need for sustainable management of fisheries was referred to in many studies (76%). However, examples of sustainable inland fisheries were only cited in two papers (Ahmed 2008; Hortle and Bamrungrach 2015), while unsustainable inland fisheries were described in four studies (Rana et al. 2009; FAO 2016; Kang et al. 2017; Funge-Smith 2018). Whilst the majority of studies (76%) contained some statistics, fewer contained actual data on fish offtake. Offtake by weight, either kg ha^{-1} or annual tonnage, was more frequently reported (46%) than by proportion of species taken (12%). Less than half the studies (44%) identified some fish species, and these were generally a list of the most commonly caught species. Artisanal or subsistence fishing was mentioned in many studies (66%), frequently within the context of the importance of inland fisheries to many people around the world. Subsistence fishing was often identified as an unquantified or hidden offtake. Similarly, recreational or sport fishing was cited quite frequently (46%) as an unreported offtake, which could have detrimental effects on the sustainability of fisheries. Recreational fishing was usually described in studies pertaining to more economically developed nations. Illegal fishing was a third source of hidden offtake. Thus, available fishing data are unlikely to accurately reflect the true wetland fisheries offtake.

Review of FAO data indicated that inland wetland fisheries account for approximately 15% of all capture fisheries, not including aquaculture (FAO 2016). Global offtake from inland fisheries has been steadily rising since 1950 when national data began to be collated, and in 2016 11.6 million tonnes were taken (FAO 2018b). Over 66% of this offtake is from Asia, with China taking nearly 2.3 million tonnes (FAO 2018b), representing the world's biggest inland fishery (Funge-Smith 2018). Africa also makes a substantial contribution to global inland fisheries (FAO 2018a).

National offtake data from inland fisheries often neglects to record subsistence activity and lacks valuable information on wetland type and species. A comparison by the World Bank (2012) using eight Asian and African countries estimates that inland fish offtake may be up to 5.9 times greater than officially reported, due partially to subsistence fishing. Lymer et al. (2016)

estimate the theoretical global inland fisheries offtake to be 6.5 times higher than official data at approximately 72 million tonnes each year, largely due to better estimates of yield and the area of global wetlands. For some countries or river basins, offtake data can be related to wetland type, but for most national statistics this information is not available and it is unclear which wetlands are included. This overlooks the importance of different wetlands for fish and fishers. For example, floodplains are the single largest source of inland fish offtake and likely comprise two thirds of the inland wetland fisheries area (Lymer et al. 2016), yet are not identified in most national statistics. Floodplains may be under-reported and often account for large increases in offtake when they are incorporated into data (Welcomme 2011), such as for Myanmar where annual fish offtake increased from 290,000 to 1.24 million tonnes between 2003 and 2012 (FAO 2016; FAO 2018a) largely because of the inclusion of floodplain fisheries. There is limited data available about the fish species taken from different wetland types, and there also seems to be disparities between the main species reported by national or more local records and those species, if any, collated internationally (e.g. by the FAO).

Case study: Reporting fish offtake in Bangladesh

Bangladesh was selected for analysis because fishing is particularly important to the country and it reports fisheries data relatively well. Over 60% of households rely on offtake of wild fish from inland wetlands for income, food, or subsistence in Bangladesh (Craig et al. 2004; Hossain and Wahab 2009), the third largest inland capture fishery globally producing 1,048,242 tonnes in 2016 (FAO 2018b). Fish are considered the most affordable and rich source of (animal) protein in Bangladesh (Galib et al. 2009). As a topographically low-lying country, almost half of Bangladesh's territory is covered by inland waters (Hossain and Wahab 2009). During the wet season, lasting 4-6 months each year, seasonal floodplains expand to cover up to 55,000 km^2 (38% of land area) (Hossain and Wahab 2009). During the dry season, the main rivers (Meghna, Ganges, Jamuna), their tributaries, and canals cover 4797 km^2 (3%); estuarine areas (incl. the Sundarbans) 5518 km^2 (4%); and large permanent or semi-permanent depressions, known locally as 'beels', amount to 1142 km^2 (1%) (Hossain and Wahab 2009).

Fish offtake from wetlands in Bangladesh is relatively well documented in annual yearbooks released by the Government Department of Fisheries (Department of Fisheries 2017), allowing critical comparison of trends. Yearbooks provide information on total fish offtake quantity and by inland wetland type such that change in offtake over time can be assessed (**Fig. 1**). Data indicate that over two-thirds of fish in wetlands in Bangladesh are taken from floodplains (Lymer et al. 2016), from which offtake in the last 13 years has fluctuated but overall increased (Fig. 1). Offtake from rivers and estuaries has also grown and there has been a slight increase in offtake from beels (Fig. 1). Additional official information includes fish offtake by district, fish species caught by weight, and percentage of catch per wetland type. Data on subsistence fishing, accounting for 53% of total offtake or 81% of offtake from floodplains, is provided separately (e.g., Department of Fisheries 2017). Subsistence fishing in Bangladesh, usually with few restrictions (Mustafa and Brooks 2008), is important especially for a minority of the population who tend to fish smaller fish, often women and children (Craig et al. 2004) and at certain locations (e.g. Dogger beel, which is mostly fished by subsistence fishers (Siddiq et al. 2013)).

Reporting of fish offtake is fraught with difficulties and limitations, especially at the species-level and comparing across different scales. Over 260 species of fish have been recorded in Bangladeshi inland waters (Rahman et al. 1999). The main groups that are commercially fished include Hilsa shad, carp and catfish, as well as prawns and shrimp (Fig. 2, Table 2) (Craig et al. 2004), with the majority of fish taken being consumed, e.g. 77 of the 81 species caught in the Chalan beel are consumed (Galib et al. 2009). Offtake of most fish has increased in recent years (Fig. 2). At national level, data on offtake resolved by species are not readily available, as species data are reported by amalgamated species categories (Table 2) and reporting is likely limited to the economically important species. Tracking change in offtake of individual species or even of species categories can be difficult, as categories and their species composition have changed over time (Table 2). Similarly, national statistics on species offtake, e.g. for beels, cannot readily be compared to data from regions and individual wetlands (Fig. 3). By aggregating data, potentially valuable information for species or sites is lost. For example, species classified as “major carp” constitute almost 30% of offtake from beels nationally yet these species are absent or comprise less than 5% from some sites (Fig. 3a). Studies of individual wetlands often include valuable data on fish diversity, offtake rates, types of fishing gear used and reasons for fishing. Discrepancies when comparing national and regional or individual wetland data are partially caused by inconsistent species classification. An example is the Ashura beel, a 252 ha wetland in north east Bangladesh, where native “other carp” are unreported at national level yet inspection of species records show comprise 30% of the catch (Fig. 3b) (Mustafa and Brooks 2008). Such data comparison highlights that regionally preferred species may go unmentioned in national statistics or aggregated in the “other fish” category (Fig. 3).

While national statistics show increases in some fish offtakes in Bangladesh, local studies suggest that illegal fishing, use of illegal gear, pollution, wetland loss and degradation and overexploitation threaten the sustainability of wetland offtakes. Declines in fish diversity have been reported at Chalan beel (Galib et al. 2009; Sayeed 2014), Bamal, Salimpur, Kola and Bashukhali (BSKB) beel (Rahman et al. 1999), Goakhola beel (Mustafa and Brooks 2008), and Tanguar Haor (Ramsar Convention 2000). Reported causes of such declines include small-meshed nets (Galib et al. 2009), poor water quality (Ahmed et al. 2009), hydraulic engineering interfering with migratory species (Halls et al. 1999), and overexploitation of larger species (Rahman et al. 1999; Ahmed 2008; Mustafa and Brooks 2008).

Waterbird offtake

Forty-one studies were identified on waterbird offtake from wetlands, of which 30 (73%) were peer-reviewed. There was a paucity of information with a global representation, with most studies (73%) based on a country, flyway, or continent. Where data were available, they were derived mainly from government statistics from more economically developed countries and apparently reflected recreational offtake. Data from less economically developed nations were limited, which may reflect ineffective regulation of bird offtake in these countries even though it is often illegal. In these countries offtake was almost always for subsistence or income generation rather than recreation (UNEP and CMS Secretariat 2014). Offtake was described as 'hunt(ing)' in almost every study (95%), often used interchangeably with 'harvest(ing)' (66%), and 'exploitation' of birds was also used occasionally (36%). 'Sustainable' was often applied (61%) as an aspiration for waterbird offtake, rather than suggesting that it is currently sustainable. There were only three studies (Sodhi et al. 2011; UNEP and CMS Secretariat 2014; Madsen et al. 2015) that reported examples of sustainable bird offtake, with four times as many examples of unsustainable offtake reported. Statistics or estimates of waterbird offtake were found in 73% of the studies. These included bag counts, illegal offtake and population indicators, and ranged from individual countries to continental estimates. Most studies (66%) encompassed all waterbirds, although there were eight studies focussed on geese and four on ducks. The most frequently articulated motive for waterbird offtake was for recreation or sport (59%) rather than for subsistence (32%). Hidden offtake through illegal hunting of waterbirds was referred to in 51% of the studies, although this was generally an acknowledgement that it was taking place, and only five studies presented any data for estimated illegal offtake (Gray and Kaminski 1994; Brochet et al. 2016; BirdLife International 2017b; Brochet et al. 2019; Ilyashenko and Mirande In prep).

Counts (or estimates) collected by governments for birds taken by legal hunting are theoretically accessible for 21 European and North American countries. These constitute a valuable resource, especially for recent years as these statistics are available online, but the national datasets are generally of variable quantity and quality. In Europe, the type of data collected, the species reported, and the temporal extent of the recording, varies greatly. For example, hunting data from Austria extending back to 1983 is available online, however the data are presented in just four broad categories for waterbirds: snipe, ducks, geese and coot (Statistik Austria 1983-2018). Records from the Czech Republic in contrast can list 13 individual species, but the time series is less detailed with many years showing data for only three species (Czech Statistical Office (CZSO) 2008-2018). Some other countries do not appear to collect or make available any official data for bird hunting, such as the UK, making it difficult to assess the sustainability of such offtake. Records of recreational hunting from the USA and Canada are relatively comprehensive, including data on ducks, geese, rails and other species. In the USA, data have been collected since the 1952/53 hunting season, and are currently collated for 41 species by state and flyway, with analyses of sex and age ratio of some species and information on the number of hunters (Raftovich et al. 2016). However, the data depend upon survey information from hunters, which relies on the accuracy of their bird identification. Christensen et al. (2017) found that hunters in Denmark asked to identify between five goose species averaged 76% accuracy. Some species were more easily identified than others (e.g. Canada goose) and adults were more accurately identified than juveniles.

Some waterbird taxa are readily identifiable and cosmopolitan, allowing comparisons between countries, and support relatively long runs of offtake data in national sets so that temporal trends can be evaluated. The mallard is probably the most hunted waterbird species, especially in more economically developed countries where recreational hunting predominates. National statistics indicate that the offtake of mallards varies greatly between countries and over many years (Fig. 4). Numbers hunted range from a few thousand in Switzerland (Eidgenössische Jagdstatistik 2019) to over five million in the USA (Canadian Wildlife Service Waterfowl

Committee 2015), no doubt related to the populations of mallards and hunters in countries of such contrasting size. However, despite some large peaks and troughs in the numbers of birds hunted over time, all countries show a decrease in offtake in recent decades (Fig. 4). The reduction in mallards taken in the USA in the 1980's may have directly reflected a declining species population at the time, but the decrease in mallards hunted since 2000 is in contrast to an increase in its population (Canadian Wildlife Service Waterfowl Committee 2015). Another explanation is that the number of people hunting has decreased, which may be the case in Canada where the number of waterbird hunters has fallen sharply since the mid-1970's (Gendron and Smith 2017), mirroring the decrease in mallards taken. However, in Hungary the number of recreational hunters (as opposed to professional hunters) has quite steadily increased from about 19,000 in 1960 to 58,000 in 2016 (Sándor et al. 2017), yet the number of mallards taken has fallen since 1989 despite a relatively stable European population (BirdLife International 2017a). Evidently, trends in offtake over time and between countries are complicated by indirect human factors, such as conservation policies and social changes.

Case study: Waterbird offtake by indigenous and recreational hunters in Canada

Canada was selected for analysis because it is estimated to support almost a quarter of the global wetland area, not including rivers and lakes (Bridgham et al. 2006), and has a tradition of hunting waterbirds. Wetlands cover approximately 1.3 million km^2, or 13% of Canada's terrestrial area (Environment and Climate Change Canada 2016). Its diverse resource of over 90,000 wetlands (Lehner and Döll 2004a; Lehner and Döll 2004b) occurs in prairies, boreal forest, along coastlines and in the tundra, and includes various types such as marshes, swamps and open water, although peatland bogs and fens dominate (Bridgham et al. 2006).

Most of the waterbird species taken in Canada are migratory (Table 3; Canadian Wildlife Service Waterfowl Committee 2017). Populations of most North American migratory birds have been declining since the 1980's (Kirby et al. 2008), although those of some species, such as Canada goose, are increasing (Sauer et al. 2013). Offtake by hunting is generally considered one of the causes of migratory species declines, such as in the Middle East and to a lesser extent Europe (Kirby et al. 2008), but the impact of offtake on North American migratory species overall is unknown (UNEP and CMS Secretariat 2014).

Canada's 172 migratory waterbird species (UNEP and CMS Secretariat 2014) are hunted by both recreational hunters and indigenous people. Canada offers a revealing perspective on waterbird offtake because of these two very different hunter communities. A larger proportion of indigenous Inuit hunt, between 30% (Joint Secretariat – Inuvialuit Settlement Region 2003) and 70% (Berkes et al. 1994; Wein and Freeman 1995), whereas less than 0.5% of the general population take part in recreational hunting (Joint Secretariat – Inuvialuit Settlement Region 2003). Wildfowl (geese, swans and ducks) are the most frequently hunted by number of individuals taken by indigenous peoples (Wein and Freeman 1995; Usher 2002). Furthermore, indigenous hunters tend to take more individuals compared to recreational hunters (Fig. 5); for example, approximately 56,000 Canada geese were taken by 1,500 Omushkego Cree, while 83,900 geese were taken by over 82,500 recreational hunters in 1993 in Ontario (Berkes et al. 1994).

Recreational hunters are required to obtain permits, so detailed hunting records of migratory birds are available in annual reports (e.g., Canadian Wildlife Service Waterfowl Committee 2017). Records on hunting have been collected by state and species, for some dating back as far as 1974, and information on population trends are available for 40 species (e.g., Canadian Wildlife Service Waterfowl Committee 2015). Less detail is generally known about offtake by indigenous people as most of those with such status are not required to obtain a licence nor are they restricted to particular seasons and bag counts, although hunting is restricted within the tribal territory (Truesdale and Brooks 2017). Strong hunting traditions are maintained in

Canada's indigenous populations as many live at least a partial subsistence way of life (Peloquin and Berkes 2009). Although indigenous people make up less than 5% of the population, approximately 35% of hunting in Canada is for subsistence purposes, much higher than the 4% in the United States and many European Countries (UNEP and CMS Secretariat 2014).

Information and insights on offtake by Canada's indigenous people can be gleaned from ethnographic studies and surveys (Berkes et al. 1994; Joint Secretariat – Inuvialuit Settlement Region 2003; Peloquin and Berkes 2009). A detailed survey of the offtake by Inuvialuit, Inuits of artic western Canada, from 1988 to 1997 provides data on the month and quantity of each species hunted, and the number of hunters (Joint Secretariat – Inuvialuit Settlement Region 2003) (**Fig. 5**a). When compared to the offtake by recreational hunters in the Northwest Territories (**Fig. 5**b), there are substantial differences in species composition. Snow goose, greater white-fronted goose and eider ducks were the largest counts year-on-year for indigenous subsistence hunters, whereas recreational hunters favoured mallard, snow goose, wigeon (a dabbling duck) and scaup (a diving duck) (**Fig. 5**). Inuvialuit hunters took a much wider variety of species than recreational hunters (Table 3). This is partially because the Inuvialuit settlements are generally coastal and therefore have access to a greater range of sea duck species, also because recreational hunters are prohibited to take some species (e.g. swans), and because the strong taste of some species (e.g. long-tailed duck) makes them less desirable to recreational hunters (Canadian Wildlife Service Waterfowl Committee 2015).

Historically in Canada, migratory waterbird hunting was seasonal and likely sustainable (Tsuji and Nieboer 1999). Migratory waterbirds were easily obtained when species returned to the same locations each year (Kristensen 2011). For example, Canada geese were traditionally harvested by the Cree of Northern Ontario when abundant in late spring (Tsuji and Nieboer 1999). As hunting and refrigeration technology advanced, diets changed and traditional knowledge and codes of conduct that prevented overexploitation have been lost, such that subsistence hunting should no longer be assumed to be sustainable. Moreover, contemporary pressures in addition to hunting may interact to impact upon waterbird populations. For example, continuous but incremental changes in climate as well as local hydroelectric development are understood to be the reasons for decreases in geese numbers rather than overexploitation at James Bay, Quebec (Peloquin and Berkes 2009).

To sustainably manage waterbird populations, comparable information on all offtake and hunters is crucial, including indigenous subsistence activity. Harvesting information was collected from indigenous people in Canada for over 40 years (Usher 2002; Joint Secretariat – Inuvialuit Settlement Region 2003), usually using questionnaires and/or interviews, but these various studies were not continued. While there is no evidence of a general lack of participation, women and children's harvests could be under-reported (Berkes et al. 1994), some hunters declined to be interviewed or became fatigued (Joint Secretariat – Inuvialuit Settlement Region 2003), and some indigenous peoples groups witheld detailed information for ethical reasons or to protect traditional knowledge (Benoit 2007). Current officially collated records are therefore probably only capturing some of the waterbird offtake in Canada; examples include the Brant goose of which 'a few thousand' are harvested by subsistence hunters, although the reported harvest is only in the hundreds (Canadian Wildlife Service Waterfowl Committee 2015), and Common eider, for which subsistence offtake is not included (Merkel and Barry 2008). Trends from the Maritimes region in southeast Canada suggest a decline in both indigenous and recreational hunting between 1993 and 2004, although the decline is less steep for indigenous peoples (Benoît 2007). However, contemporary published research on indigenous harvesting is lacking, which would be important to assess recent trends in waterbird offtake.

Conclusions

Wetlands globally provide extremely valuable provisioning services and are biologically diverse. Offtake represents a pressure on wetlands that has not been evaluated, but this systematic review of the literature and data sources revealed the following critical issues for fish and waterbirds.

Semantics

There is a diverse lexicon associated with offtake in the literature and this is applied inconsistently between taxa. For example, while similarities were found between fish and bird taxa in the ubiquitous use of the term ‘harvest’, the term ‘exploit’ appeared to have different connotations and frequency of use. Within fishery studies, exploit was used often and in general to describe fish as a resource, unless over-exploitation was explicitly stated. Within studies of waterbird offtake, exploit was used less frequently and was more likely to have a negative association.

Data availability and quality

There is a paucity of data globally for waterbird offtake, and especially for less economically developed countries, while fishing data from inland waters are collected globally by the FAO (e.g. FAO 2018a). Nearly all data for both fish and bird offtake used in studies are derived from government sources. However, data quality for both taxa are variable with species or site information lacking, including for fish offtake from floodplains which are by far the most important inland fisheries (Lymer et al. 2016). Long-term fish and bird records are often incomplete or inconsistent, making monitoring of offtake and populations difficult. Information on the type of wetland providing the offtake is also frequently absent, potentially hampering conservation priorities and policies. Where data are absent, for example when Governments fail to collect or publish data, there is a reliance on estimates for larger-scale geographic areas.

Disparities between records

Offtake records collected locally, nationally and internationally are frequently incomparable because they are not reported consistently. The aggregation of data for national statistics is common, such as amalgamating carp species in fisheries and ducks and geese for waterbirds, and may be a response to variable data recording. However, it can lead to the loss of important information, such as hunting pressure on individual species, some of which may be rare.

Hidden offtake and by-catch

Hidden offtake, which is unreported and frequently illegal, is widely recognised as a problem. It hinders obtaining accurate values for offtake and official statistics are highly likely to be a substantial undercount. Subsistence, recreational or sports fishing, and fishing by illegal methods, are the main sources of hidden offtake for fish in wetlands. Illegal shooting and trapping are the main activities for hidden offtake of birds. Estimates of the amount of hidden offtake for fish and birds from wetlands are not available, but clearly this may be a serious pressure on species. Official figures suggest that legal fish offtake is increasing (FAO 2018b) while migratory waterbirds are declining (Kirby et al. 2008), even if the hunting of waterbirds in North America at least may be decreasing (U.S. Department of the Interior et al. 2016).

Offtake may result in significant numbers of animals taken as by-catch. Although this review did not specifically include this issue, it is known that the by-catch of fishing may include birds, turtles and macroinvertebrates (Davies et al. 2009) and that by-catch represents a threat to vertebrate species at risk of extinction (Ripple et al. 2019).

Socio-economic and cultural factors

Reported offtake of birds is most frequently for the purpose of sport or recreation, while fish offtake (that was not commercial) is mainly to support subsistence fishers. This difference reflects the trend for waterbird data to originate from more economically developed countries with studies on fish offtake more likely from less economically developed nations, where the largest inland fisheries tend to be found. Within countries, different communities may target different species for offtake, based upon cultural traditions, and differentially contribute to official data reporting. Such socio-economic and cultural factors may make comparisons between taxa or within countries challenging, and may require participatory methods to gather necessary information (e.g. Wiber et al. 2004).

Sustainability

Studies of fish and birds frequently refer to the need for sustainable management of fishing and hunting, but unsustainable practices are more likely to be indicated in the literature than sustainable ones. Nevertheless, authors are inclined to show caution in suggesting current offtake is unsustainable, most likely due to underreporting and incomplete data on offtake, along with a lack of reliable population statistics, making it difficult to accurately assess sustainability. The overexploitation of species could clearly affect population viability and risk extinction, and it could also affect ecosystem functioning and services. The loss of provisioning services in wetlands will reduce food availability and income, and may impact income from tourism and recreation, affecting some of the most impoverished people in less economically developed countries (Millennium Ecosystem Assessment 2005). Wetland animals may be particularly at risk from overexploitation due to the fragmented and isolated nature of many wetlands, which makes it difficult for some species to move between them (Brinson and Malvárez 2002) and maintain a viable population (He et al. 2017). Moreover, many waterbirds are migratory, moving between countries along transcontinental corridors known as flyways. National datasets do not capture all offtake along the flyway, leading to a lack of integrated understanding and management of international bird populations. Management is further complicated by the diversity of customs and cultures represented along the flyway, and by the different legislation and policies on hunting practised by countries, making sustainable offtake of migratory bird species particularly problematic (Madsen et al. 2015).

Examples of sustainable offtake for fish and waterbirds are rare in the literature. The Svalbard-breeding population of the pink-footed goose has an internationally coordinated adaptive hunting management framework along its relatively short Northern European migratory flyway (Clausen et al. 2017). Evidence suggests that offtake has not affected population growth but still caution is recommended due to variable data availability in countries along the migratory corridor and potential population inertia in long-lived species such as geese (Clausen et al. 2017). Management plans may provide a useful tool for control of offtake to achieve sustainability targets. For example, the North American Waterfowl Management Plan, which implemented sustainable harvesting and wetland protection and restoration programs across Canada, USA and Mexico, has probably helped reverse the waterbird population declines of the 1980's by restricting hunting to allow recovery (North American Waterfowl Management Plan 2012).

Further research

An accurate evaluation of the global offtake from wetlands requires data for species and sites recorded consistently over many years; it is evident from this review that, other than for a very few cases, such information is lacking. This study has shown that reliable data on wetland offtake is at best patchy over space and time and at worst absent, similar to terrestrial wild animal offtake (e.g. Ingram et al. 2015; Joppa et al. 2016). Data gaps and insufficiencies are often due to unreported and illegal offtake, or inconsistent or aggregated reporting, while comparison between different communities and countries is difficult when data are not standardised. One solution to data gaps and variabilities is modelling, based on estimates extrapolated from known data sources (e.g. as done for terrestrial offtake Ziegler et al. 2016; Benítez-López et al. 2019). Thus, where data are available, these could be used to model offtake in other areas and over time periods where data are scarce, and thereby used to not only estimate global offtake of for wetlands but also to predict offtake in the future. Modelling may also allow integration of data on other pressures that interact with offtake to pose cumulative or synergistic threats to species. In this review, for example, specific studies were found that reported waterbird deaths from poisoning by lead shot as an indirect consequence of hunting (Andreotti et al. 2018), but these were not included in national statistics for offtake.

Further research to assess the global offtake from wetlands is overdue because current levels and trends are not known, although this study suggests wild fish offtake may be increasing and offtake represents a potentially significant pressure on species and biodiversity. Given the importance of wetland offtake for provisioning services, the sustainable management of wetland resources is vital to prevent biodiversity loss and food poverty to some of the world’s most vulnerable people (Millennium Ecosystem Assessment 2005). Better information on offtake would support monitoring and refinement of global conservation and development policies, such as the Aichi Biodiversity targets (UNEP and CBD 2010) and Sustainable Development Goals (UN General Assembly 2015), as well as facilitate better management plans, species and site protection, and restoration initiatives for wetlands.

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Conflict of interest The authors declare that they have no conflict of interest.

Figures legends and tables

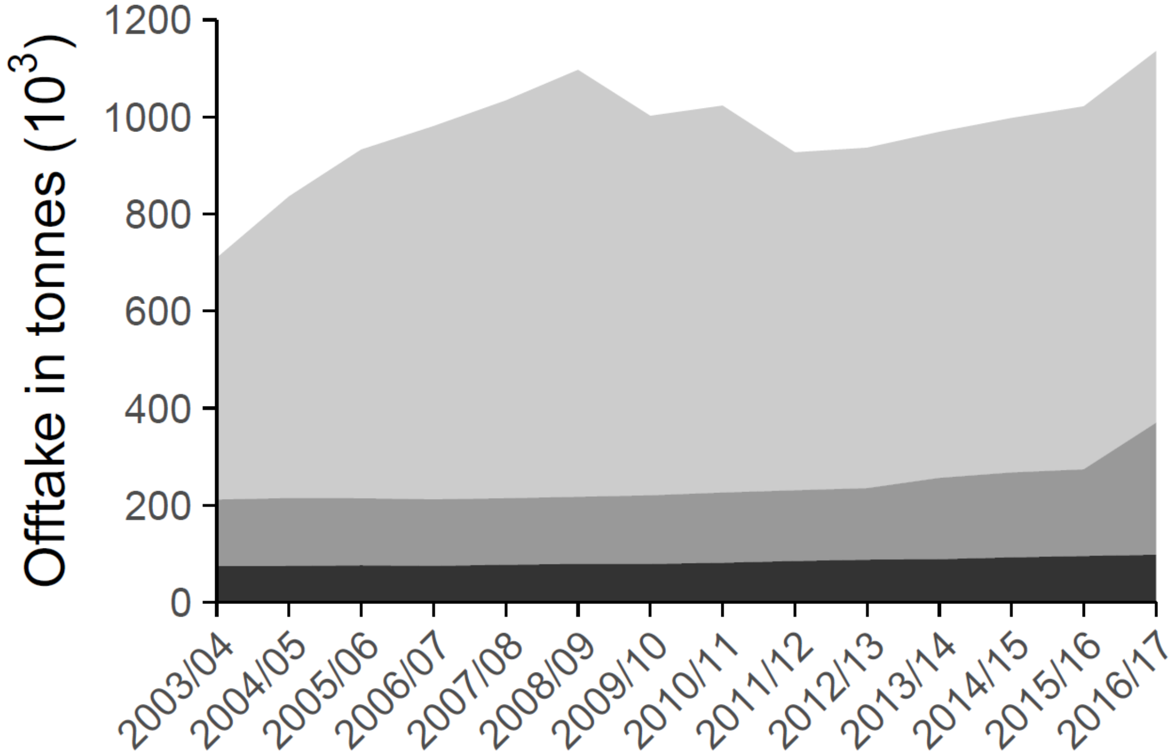

Fig. 1 Total fisheries offtake from beels (black), rivers and estuaries (dark grey) and floodplains (light grey) in Bangladesh between 2003 and 2017. Bangladesh fisheries yearbooks provide data for Kaptai Lake and Sundarbans as inland waters; these are excluded here as Kaptai Lake is man-made and the Sundarbans are saline mangrove systems. Data from Department of Fisheries (2004-17)

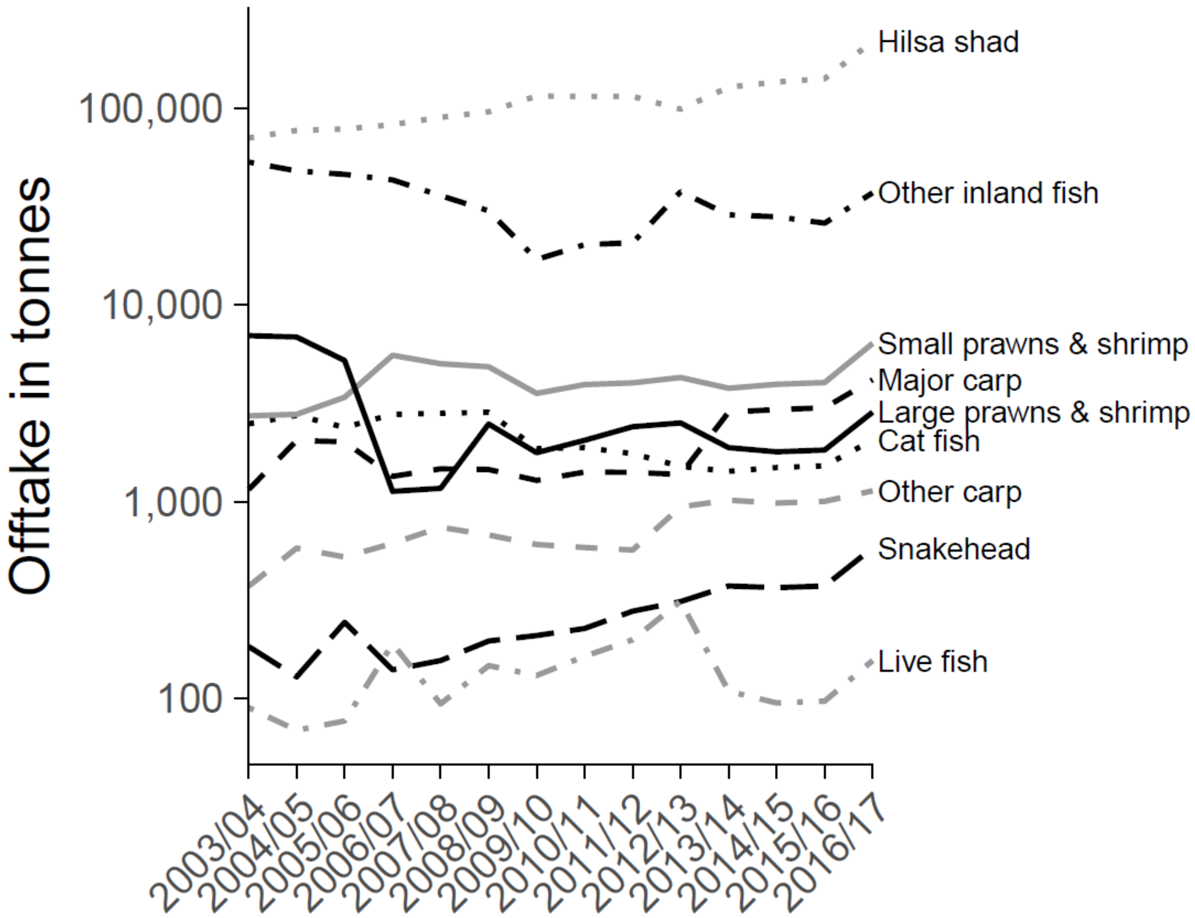

Fig. 2 Offtake of the major groups of fish and crustaceans in rivers and estuaries of Bangladesh from 2003 to 2017. Data from Department of Fisheries (2004-17). See Table for species information

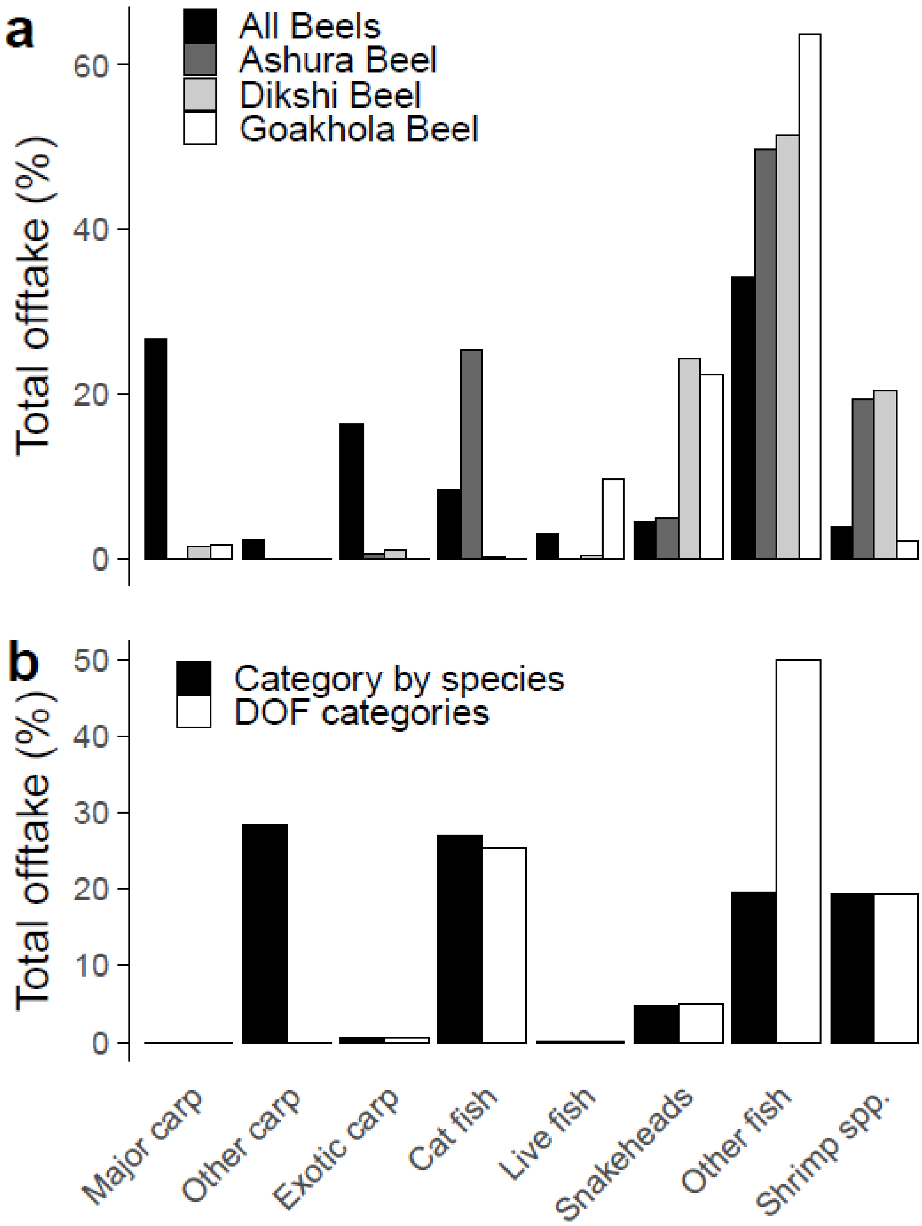

Fig. 3 Comparisons of fisheries offtake (aggregated over 1997-2002) between (a) all beels in Bangladesh (black bars, data from Department of Fisheries (2004) and three individual beels, Ashura (dark grey), Diskshi (light grey) and Goakhola (white) (data from Mustafa and Brooks (2008), with species grouped by national categorization from Department of Fisheries (DOF), and (b) categories for Ashura beel containing all species taken as assigned to national DOF categories by the authors (black bars) and species officially reported in national DOF categories (white bars), for which many species are aggregated into "other fish". Note: no major carp species were taken at this location. Species lists by DOF categories are shown in Table 2

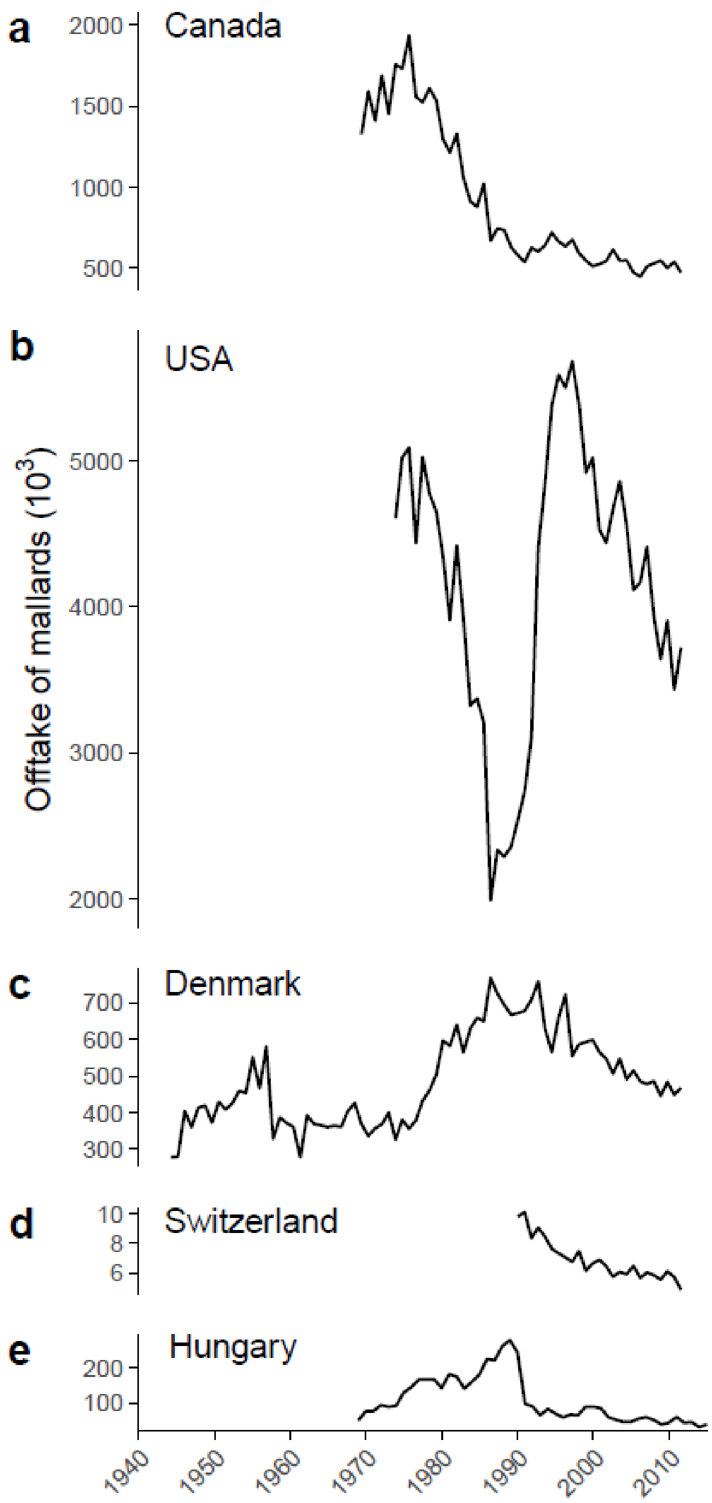

Fig. 4 Number of mallards taken according to national hunting statistics for (a) Canada and (b) USA (Canadian Wildlife Service Waterfowl Committee 2015), (c) Denmark (Danish Centre for Environment and Energy 2019), (d) Switzerland (Eidgenössische Jagdstatistik 2019) and (e) Hungary (Sándor et al. 2017)

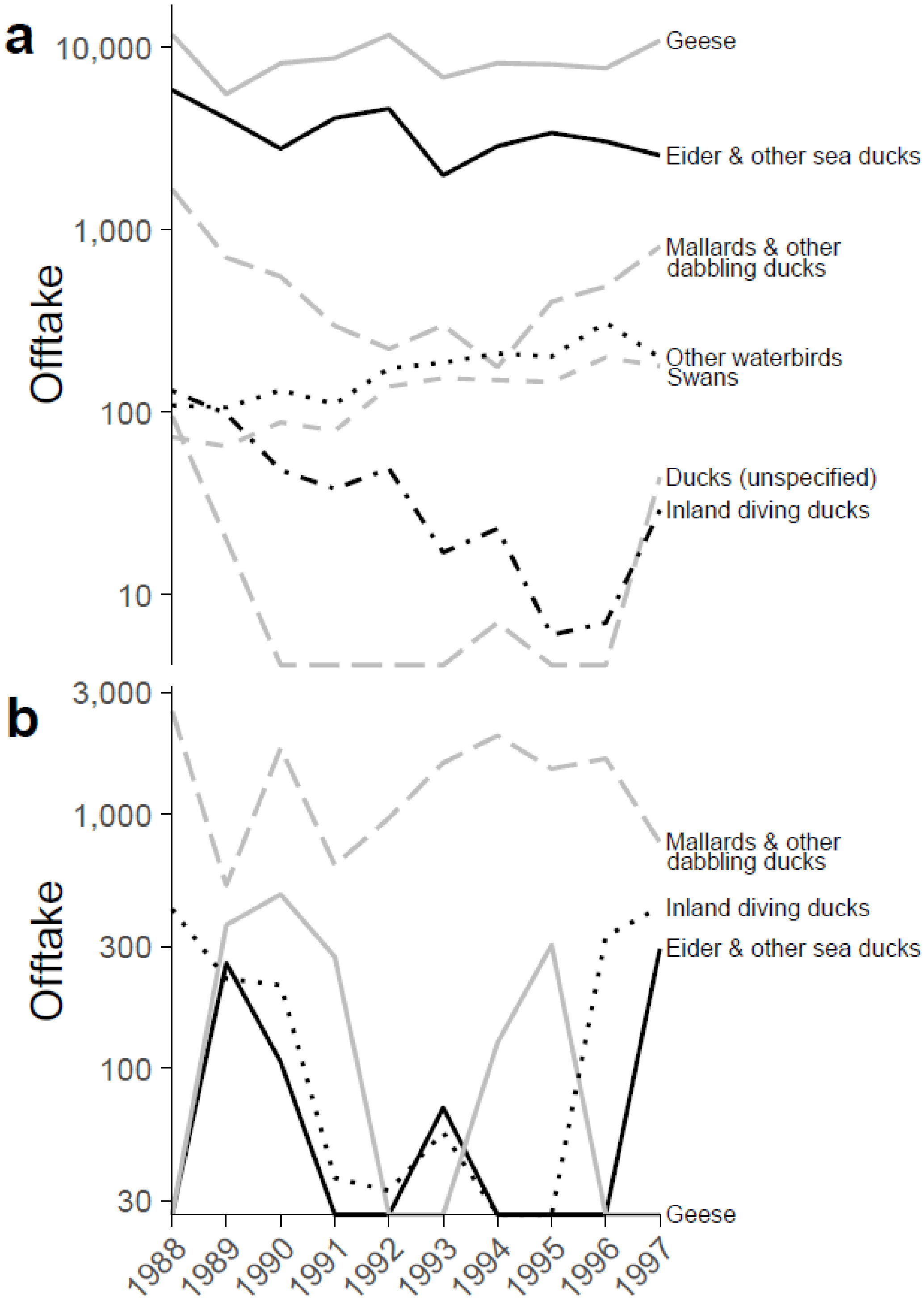

Fig. 5 Offtake of waterbirds (number of individuals) from 1988 to 1997 in Canada by (a) Inuit indigenous hunters in the Inuvialuit settlement region (Joint Secretariat – Inuvialuit Settlement Region 2003) and (b) recreational hunters in the Northwest Territory (Government of Canada 2017). Species lists by categories are shown in Table 3

Table 1 Target words used in Web of Science and Google Scholar searches

Offtake theme	Wetland theme	Fish theme	Waterbird theme
Bag(s)	Wetland(s)	Fish(ing/er/ery)	Waterbird(s)
Count(s)	Floodplain(s)	Inland	Wader(s)
Offtake	Swamp(s)	Stock	Duck(s)
Harvest(ing)	Pothole	Recreation(al)	Geese
Exploit(ation)		Sport	Anatidae
(Un)sustainable			Waterfowl
Hunt(ing/er)			Flyway(s)
Subsistence			
(Il)legal			

Table 2 Fish species categorised by the Department of Fisheries yearbooks for Bangladesh. Exotic carp are not recorded in rivers and estuaries, while Hilsa shad is not found in beels and floodplains. This table uses the categories as represented in the 2016/17 yearbook, although species have been moved between categories, and categories have been added or removed, since 2003/04. Data from Department of Fisheries (2017)

Category	Common names (Bengali)	Scientific names
Major carp	Rui	*Labeo rohita*
	Catla	*Catla catla*
	Mrigal	*Cirrhinus mrigala*
Other carp	Kalibaus	*Labeo calbasu*
	Bata	*Labeo bata*

	Gonia	*Labeo gonius*
Exotic (non-native) carp	Silver	*Hypophthalmichthys molitrix*
	Grass	*Ctenopharyngodon idella*
	Common or Mirror	*Cyprinus carpio*
	Big head	*Hypophthalmichthys nobilis*
	Black	*Mylopharyngodon piceus*
Catfish*	Pangas	*Pangasius pangasius*
	Boal	*Wallago attu*
	Air	*Sperata aor*
	Silon	*Silonia silondia*
	Rita	*Rita rita*
Snakeheads	Shol	*Channa marulius*
	Gazar	*Channa striatus*
	Taki	*Channa punctatus*
Live fish#	Koi	*Anabas testudineus*
	Shingi	*Clarias batrachus*
	Magur	*Heteropneustes fossilis*
Other inland fish	Includes:	Includes:
	Sarpunti	*Systomus sarana*
	Thai sharpunti	*Barbonymus gonionotus*
	Punti spp.	*Puntius* spp.
	Chapila	*Gudusia chapra*
	Tengra	*Mystus* spp.
	Pabda	*Ompak pabda*
	Baim	*Mastacembelus* spp.

	Mola	*Amblypharyngodon mola*
Hilsa shad	Ilish	*Tenualosa ilisha*
Large prawns &	Bagda	*Penaeus monodon*
shrimp+	Galda,	*Macrobrachium rosenbergii*
	Harina	*Metapenaeus monoceros*
	Chaka	*Fenneropenaeus indicus*
Small prawn & shrimp+	Includes:	Includes:
	small Chingri	Decapoda

*from 2013/14 catfish have been divided into two categories: Pangas and other catfish, which includes four other species

fish that are sold alive (Craig et al. 2004)

+ the terms prawn and shrimp have been used interchangeably since 2003/04

Table 3 Wildfowl and other waterbird species taken by recreational and Inuvialuit hunters in Canada. Information from Joint Secretariat – Inuvialuit Settlement Region (2003) and Government of Canada (2017)

Categories	Species		Offtake	
	Common name	Scientific name	Recreational	Inuvialuit
Geese	Canada	*Branta canadensis*	x	x
	Snow	*Chen caerulescens*	x	x
	Greater white-fronted	*Anser albifrons*	x	x
	Brant	*Branta bernicla*		x
	Ross's	*Chen rossii*		x
Mallard	Mallard	*Anas platyrhynchos*	x	x
Other dabbling ducks	Northern pintail	*Anas acuta*	x	x
	Green-winged teal	*Anas crecca*	x	x
	American wigeon	*Anas americana*	x	x
	Shoveler	*Anas clypeata*	x	x
Inland diving ducks	Canvasback	*Aythya valisineria*	x	x
	Scaup sp.	*Aythya* sp.	x	x
Eider and other sea ducks	Eider sp.	*Somateria* sp.	x	x
	Scoter sp.	*Melanitta* sp.	x	x
	Goldeneye sp.	*Bucephala* sp.	x	x
	Long-tailed duck	*Clangula hyemalis*		x
	Merganser sp.	*Mergus* sp.		x
Swans	Trumpeter	*Cygnus buccinator*		x
	Tundra	*Cygnus columbianus*		x

	Other unspecified	*Cygnus* spp.	x
Other	Sandhill crane	*Grus canadensis*	x
waterbirds	Loon sp.	*Gavia* sp.	x

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Supplementary Material

Global offtake of wild animals from wetlands: critical issues for fish and birds

Sarah Brotherton • Chris B. Joyce • Jörn P. W. Scharlemann

Table S1 List of studies for fish offtake in wetlands

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